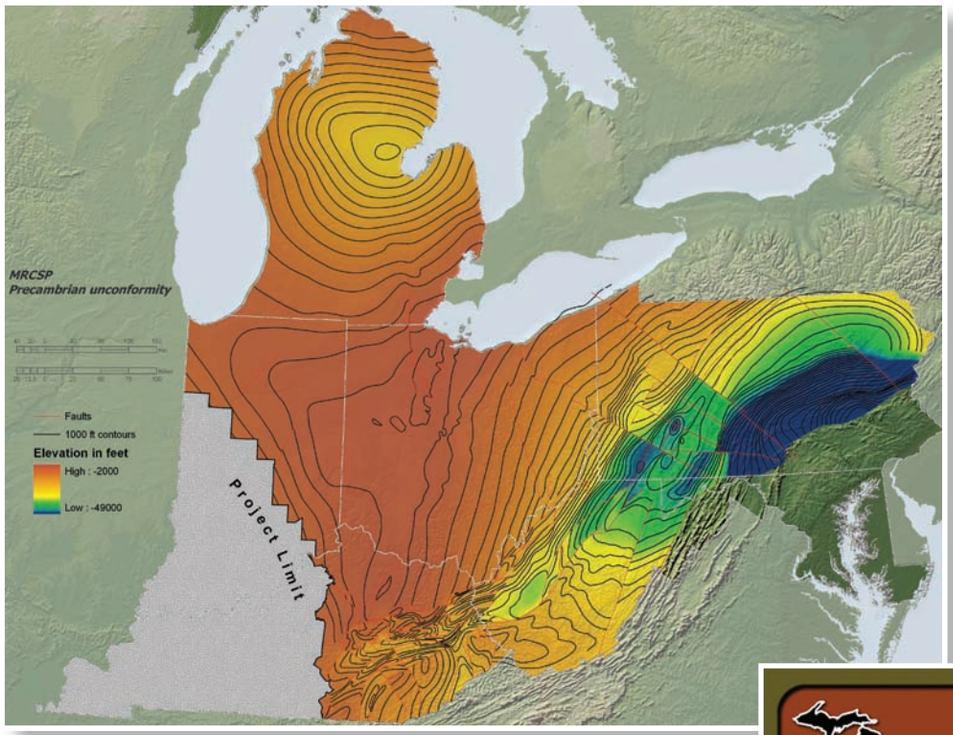


CO_2 pipeline from a gas processing plant in Michigan.

Midwest Regional Carbon Sequestration Partnership

The Midwest Regional Carbon Sequestration Partnership (MRCSP) was formed to assess the regional technical potential, economic viability, and public acceptability of carbon sequestration. The MRCSP Region consists of seven contiguous states: Indiana, Kentucky, Maryland, Michigan, Ohio, Pennsylvania, and West Virginia. The MRCSP includes more than 30 organizations from the research community, energy industry, universities, non-government, and government organizations. The Region has a diverse range of CO_2 sources and many opportunities for geologic and terrestrial sequestration.

Potential locations for geologic sequestration in the Region include deep rock formations associated with broad sedimentary basins. Initial assessments show the presence of numerous geologic units in the area and delineated the most promising geologic reservoirs for CO_2 sequestration. The geologic surveys from seven states worked together to complete the geologic assessment. In total, the geologic assessment resulted in 30 original depth and thickness maps, 9 regional thematic maps, and 14 capacity maps, using data from more than 85,000 control-points stored in a state-of-the-art geographic information system available for interactive use on the team's website (www.mrcsp.org). These maps and data indicate that deep saline formations, oil and gas reservoirs, organic shale layers, and coalbeds have a combined capacity to permanently contain hundred's of years of CO_2 emissions from the Region.

MRCSP research on terrestrial carbon sequestration focused on five dominant land use types identified by the research team as offering the best opportunities for the Region. These land use categories included traditional noneroded cropland, eroded cropland, marginal lands, mineland areas, and wetlands. The specific objectives of the research were to quantify the carbon sequestration capacity of the major land use components and to identify land use and management options to achieve maximum capacity such as improved agricultural practices, reforestation, and reclaiming mineland.

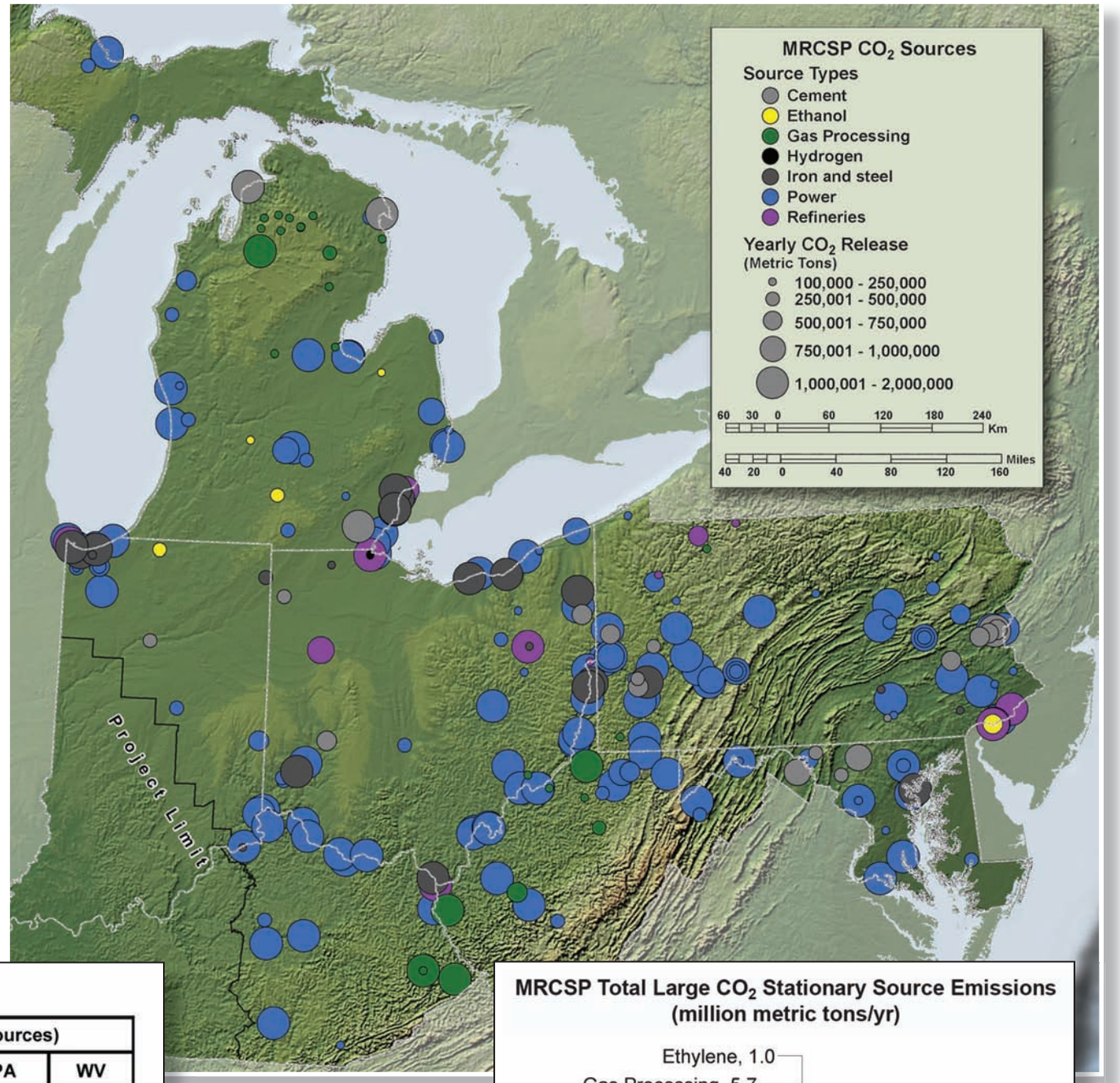
A Snapshot of the MRCSP Region

The MRCSP Region includes

- 7 states: Indiana, Kentucky, Maryland, Michigan, Ohio, Pennsylvania, and West Virginia
- Population: 50.8 million (1 in 6 Americans)
- Gross Regional Product: $1,534 billion (1/6 U.S. economy)
- 21.5 percent of all electricity generated in the U.S.
- 77 percent of electricity generated in the Region is generated by coal
- 12 percent of nation's total CO_2 emissions

CO_2 Sources in the MRCSP Region

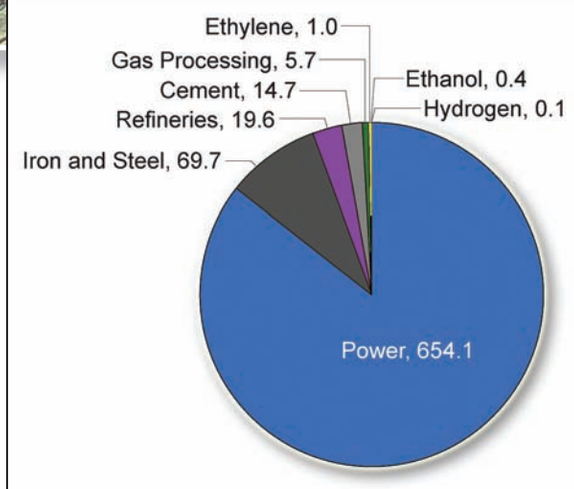
Due to its large and diverse economy, the MRCSP Region includes a large variety of GHG sources. While distributed sources such as agriculture, transportation, and heating account for 34 percent of CO_2 emissions in the MRCSP Region, 66 percent of CO_2 emissions are linked to large stationary sources. More than 750 million metric tons (827 million tons) of CO_2 is emitted each year from these large, fixed stationary sources including power plants, refineries, cement plants, and iron and steel plants. Emissions are highest along the Ohio River Valley and coastlines where many power plants and industries are located. In the MRCSP Region, 85 percent of CO_2 stationary source emissions are from electrical power plants.

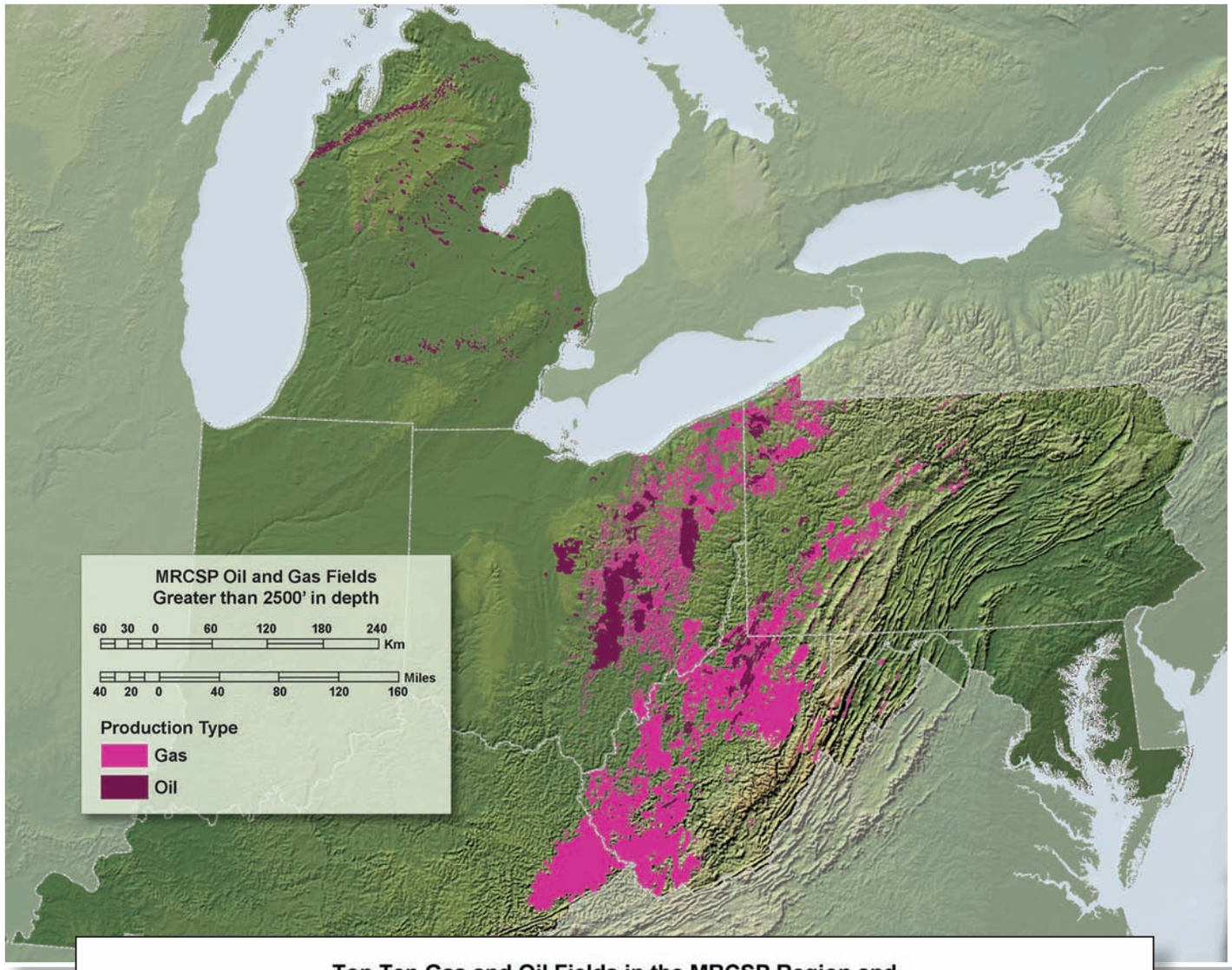


CO_2 Emissions from Large Point Sources in MRCSP Region

Category	Large CO_2 Point Source Emissions in million metric tons CO_2/year (# sources)								
	MRCSP	MRCSP%	IN	KY	MD	MI	OH	PA	WV
Power	654.1 (207)	85.5%	124 (33)	93 (22)	32 (15)	76 (33)	127 (31)	116 (55)	86 (18)
Iron and Steel	69.7 (23)	9.1%	26.4 (7)	2.4 (2)	4.5 (1)	11.8 (3)	17.4 (7)	3.2 (2)	4.0 (1)
Refineries	19.6 (14)	2.6%	4.2 (2)	2.1 (1)	0 (0)	0.7 (1)	5.3 (4)	7.2 (5)	1.1 (1)
Cement	14.7 (23)	1.9%	2.4 (4)	0.5 (1)	1.5 (3)	3.5 (3)	1.4 (3)	4.6 (8)	0.8 (1)
Gas Processing	5.6 (9)	0.7%	0 (0)	0.4(2)	0 (0)	1.2 (2)	0 (0)	0.1 (1)	3.9 (4)
Ethylene	1.0 (3)	0.1%	0 (0)	0.5 (2)	0 (0)	0 (0)	0 (0)	0.5 (1)	0 (0)
Ethanol	0.4 (2)	0.1%	0.3 (1)	0 (0)	0 (0)	0.1 (1)	0 (0)	0 (0)	0 (0)
Hydrogen	0.1 (1)	0.0%	0 (0)	0 (0)	0 (0)	0 (0)	0.1 (1)	0 (0)	0 (0)
Total	***765 (282)***	***100%***	***157 (47)***	***98 (30)***	***38 (19)***	***93 (43)***	***152 (46)***	***132 (72)***	***95 (25)***

MRCSP Total Large CO_2 Stationary Source Emissions (million metric tons/yr)





Top Ten Gas and Oil Fields in the MRCSP Region and Calculated CO_2 Storage Capacities

Field Name	State	Producing Formation	Average Depth (ft)	#Wells	Acres	CO_2 Storage Potential (million metric tons)
South Burns Chapel	WV	Oriskany-Hrbrg	7,634	130	64,046	341
Elk-Poca (Sissonville)	WV	Oriskany	5,032	1,121	244,733	330
Volant	PA	Medina	6,050	353	31,451	310
Weston-Jane Lew	WV	Devonian Shale	3,179	292	56,137	258
E. Canton Consolidated – S	OH	Clinton	5,300	1,290	120,430	251
N. Ellsworth Consolidated	OH	Clinton	5,100	662	108,919	245
Baltic	OH	Rose Run	6,390	113	84,083	232
Weston	WV	Devonian Shale	4,336	553	63,714	196
Roaring Run	PA	Devonian Shale	2,600	355	21,400	176
Belington	WV	Devonian Shale	4,169	552	53,877	172

MRCSP Oil and Gas Resevoirs

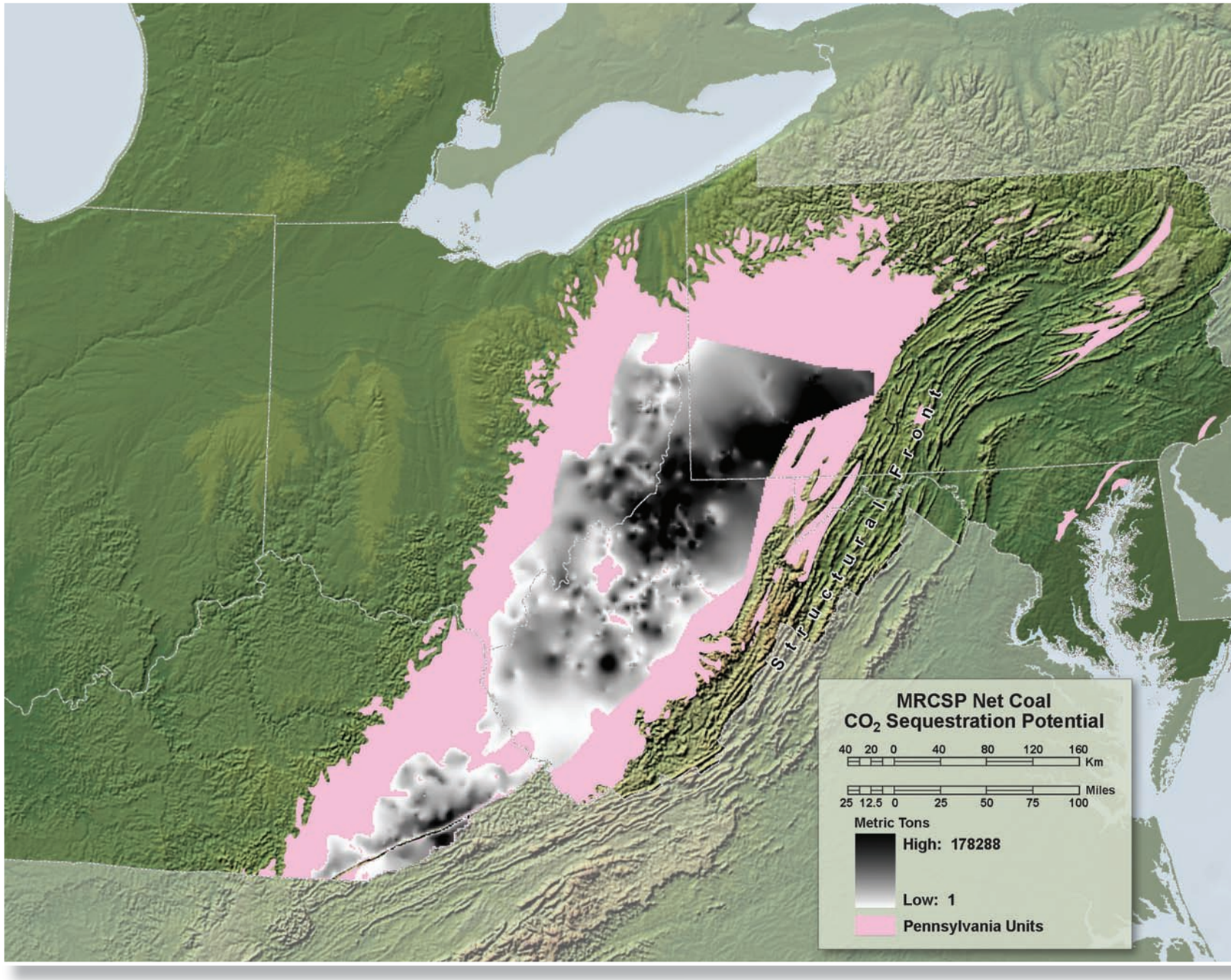
The MRCSP Region has many opportunities for CO_2 sequestration in oil and gas reservoirs. Exploration for oil in the Region began in 1859 with the discovery of oil by Colonel Drake in Oil City, Pennsylvania. Since that time, the MRCSP Region has produced more than 0.8 billion m^3 (5 billion barrels) of oil and more than 7.9 trillion m^3 (50 trillion cubic feet) of natural gas. In addition, significant amounts of natural gas are stored in the Region. Such large volumes of gas storage capacity (both natural and engineered) strongly suggest that CO_2 gas can be successfully managed in subsurface reservoirs within the Region. The oil and gas fields in the Region are most concentrated in the Appalachian and Michigan sedimentary basins. Research suggests that oil and gas fields have a potential sequestration capacity of at least 2,500 million metric tons (2,760 million tons) of CO_2. Much of this capacity is intermixed with deep saline formations. In fact, it may be difficult to differentiate the two in many areas.

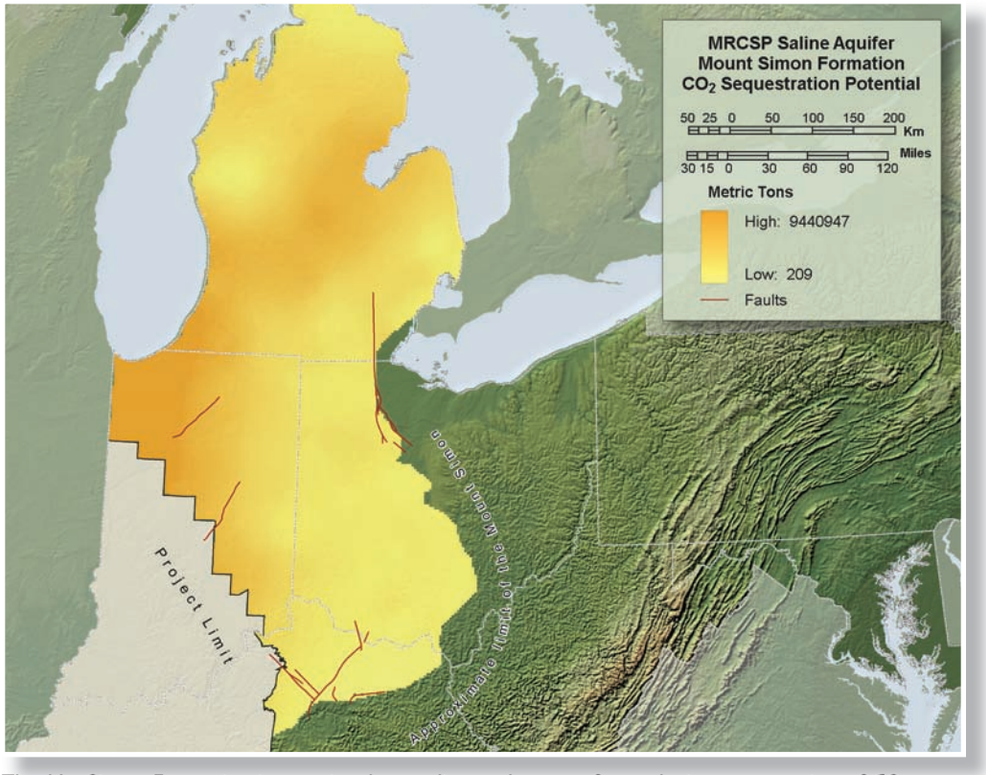
Oil and gas reservoirs cover large portions of the Appalachian basin with significant fields in eastern Ohio, western Pennsylvania, western West Virginia, and eastern Kentucky. Key oil and gas rock formations in the Appalachian Basin include Devonian Shales, "Clinton"/Medina/Tuscarora sandstones, the Oriskany Sandstone, and the Rose Run Sandstone. Within the Michigan basin, oil and natural gas reservoirs are concentrated along the Niagaran reef trend and Devonian Antrim Shales in the northwestern margin of the Basin and the southern margin of the Basin. Enhanced oil recovery with CO_2 has only been applied in a few fields in the Region. However, studies have suggested that a large amount of oil and gas remains in place in many reservoirs. Thus, potential is high for enhanced oil and gas production associated with CO_2 sequestration in the MRCSP Region.

MRCSP Unmineable Coal Beds

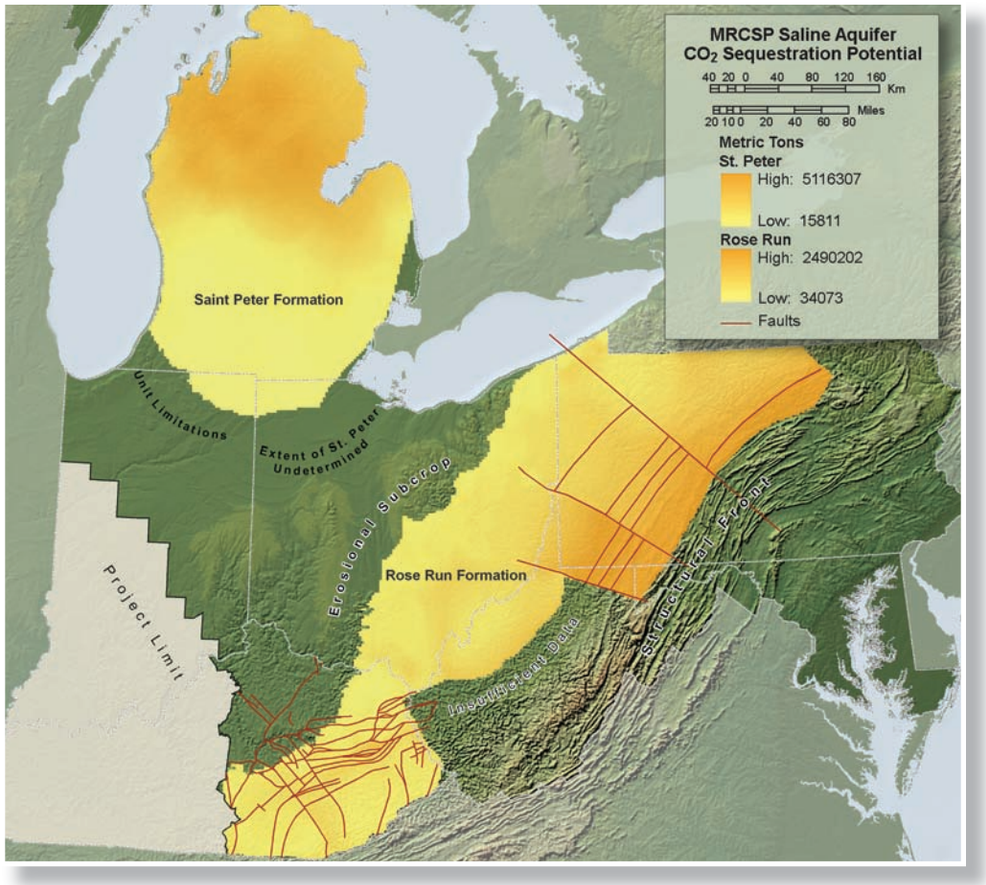
The MRCSP Region contains the second- (West Virginia), third- (Kentucky), fourth- (Pennsylvania) and fourteenth- (Ohio) leading coal-producing states in the nation. Bituminous coal beds are located in the Appalachian and Michigan basins and anthracite coal beds are located in Pennsylvania. Portions of these coal beds are considered "unmineable" because they are either located too deep below the ground or the coal seams are too thin to mine. Analysis of coal beds in the MRCSP Region indicate that it may be possible to sequester up to 1,000 million metric tons (1,100 million tons) of CO_2 in unmineable coal beds in the Appalachian Basin alone. Deep unmineable coal beds in the Appalachian basin with the highest capacity for CO_2 sequestration are located along the Ohio River Valley in Kentucky, Ohio, Pennsylvania, and West Virginia.

The potential exists for using CO_2 for ECBM recovery in coal beds in the Appalachian basin. In the past decade, significant CBM production has occurred in some of these historic "gassy" coals, particularly in southern West Virginia. CBM is locally produced from at least 24 pools in Pennsylvania, and historic and modern CBM fields also occur in the northern portion of West Virginia. Historically, CBM production took place in eastern Kentucky, and it is reported as taken place in Ohio as early as 1924. Although interest in CBM production and exploration is growing in the basin, vast areas remain untested—as well as their CO_2 sequestration potential—and much of the existing data vital in understanding CBM systems is not publicly available.





The Mt. Simon Formation is a major deep saline rock target for geologic sequestration of CO_2.



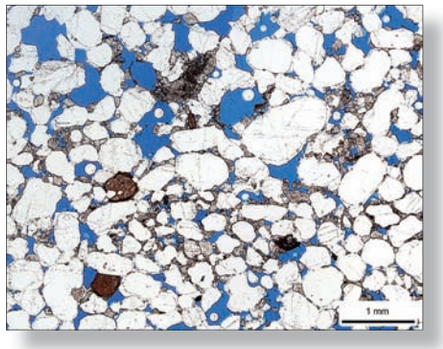
Saint Peter and Rose Run formations are other deep saline rock targets for carbon sequestration.

MRCSP Deep Saline Formations

Deep saline rock formations are, by far, the MRCSP Region's largest assets for long-term geologic CO_2 sequestration. Initial mapping indicates that the Region's well-defined deep saline formations could potentially sequester up to 189,000 million metric tons (208,000 million tons) of CO_2. The estimated CO_2 storage capacity for the Region is very large compared to the present-day emissions, enough to accommodate CO_2 emissions from large stationary sources in the Region for hundreds of years. Saline formations in the MRCSP Region are widespread, close to many large CO_2 sources, and are thought to have large pore volumes available for injection use. However, storage capacity is not evenly distributed across the Region.

Thick sequences of sedimentary rocks are present throughout most of the MRCSP states in the form of broad basins and arches. The rocks are saturated with dense brine fluids. In addition, the Region is considered a fairly stable geologic setting. The rock formations have been correlated and mapped in the Region in stratigraphic charts based primarily on rocks encountered in oil and gas wells. This data was used to characterize geologic sequestration opportunities in deep saline formations throughout the Region.

The storage capacity in each reservoir is largely a function of its spatial extent, thickness, and porosity. Given its presence in much of the MRCSP Region, the saline formation with the largest capacity in the Region is the Mt. Simon Sandstone, followed by the St. Peter Sandstone and the Medina/Tuscarora Sandstone. Other notable target formations include the Rose Run Sandstone, the Oriskany Sandstone, and the Sylvania Sandstone. In addition to these storage options, the Region may have several other attractive options, however, due to a lack of existing exploratory wells in many areas, such as in the deepest portion of the Appalachian basin in Pennsylvania, the potential storage capacity in some areas of the MRCSP Region could not be accessed. While Michigan has the highest storage potential, all of the seven states in the MRCSP Region have the capacity to store large amounts of CO_2 in deep saline formations.



Thin section microscope view of pore space (shown in blue) of the Rose Run sandstone.

Estimated CO_2 Storage Potential in Major Deep Saline Formations in the MRCSP Region

Deep Saline Target	Estimated Capacity (million metric tons CO_2*)
Mt. Simon Formation	86,900
St. Peter Sandstone	35,300
Medina/Tuscarora Sandstone	28,200
Rose Run Sandstone	19,700
Oriskany Sandstone	7,800
Sylvania Sandstone	6,000
Wastegate Formation	1,800
Basal Conasauga Sandstones	1,700
Potsdam Sandstone	700
Rome Trough Sandstones	500
Total Deep Saline	***189,000***

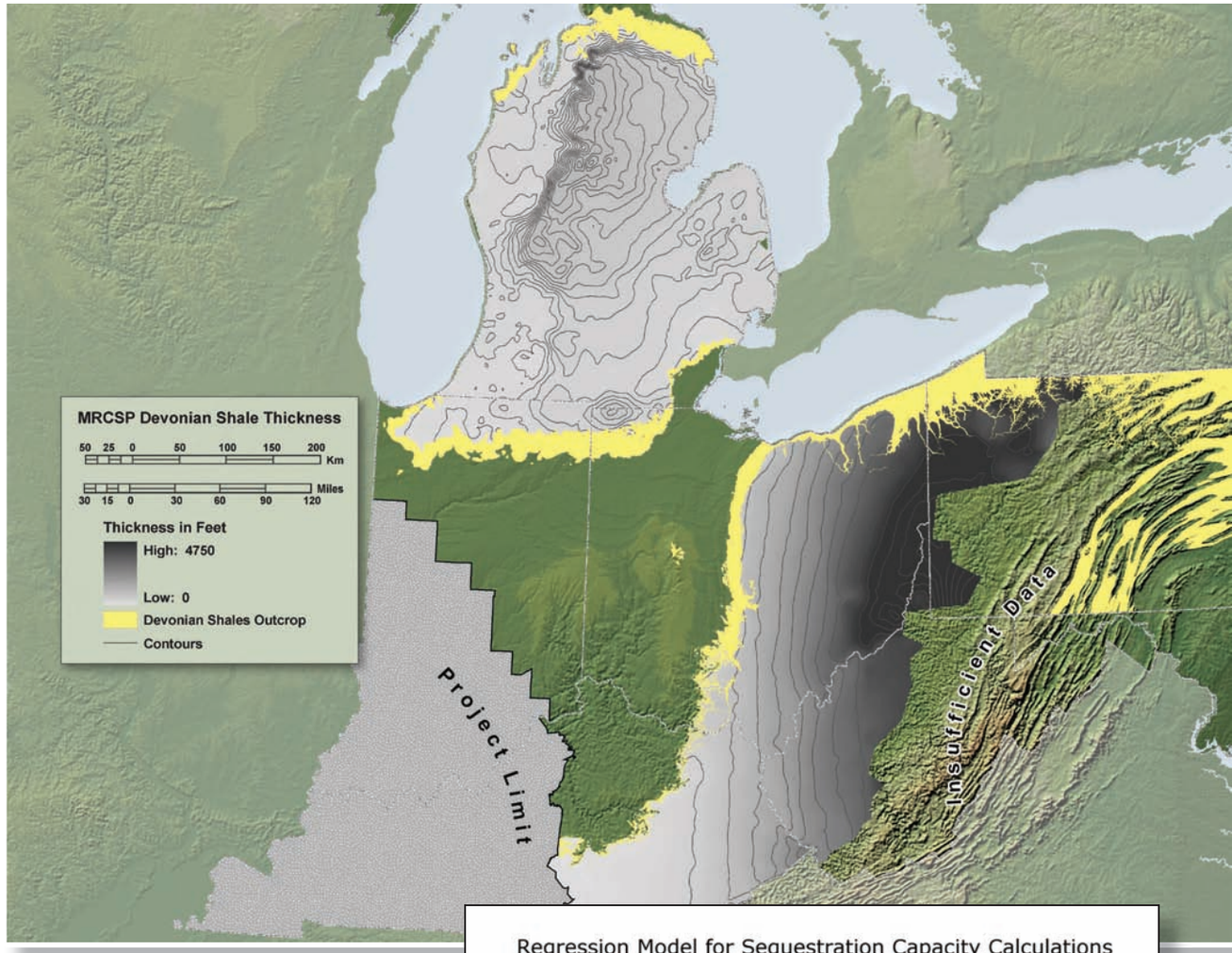
*Based on National Atlas Methodology P85%.

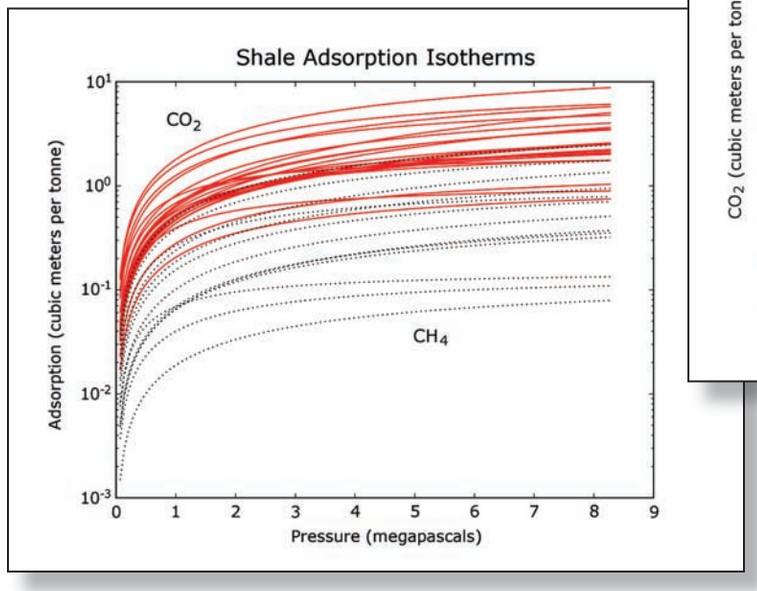
MRCSP Deep Organic-Rich Shales

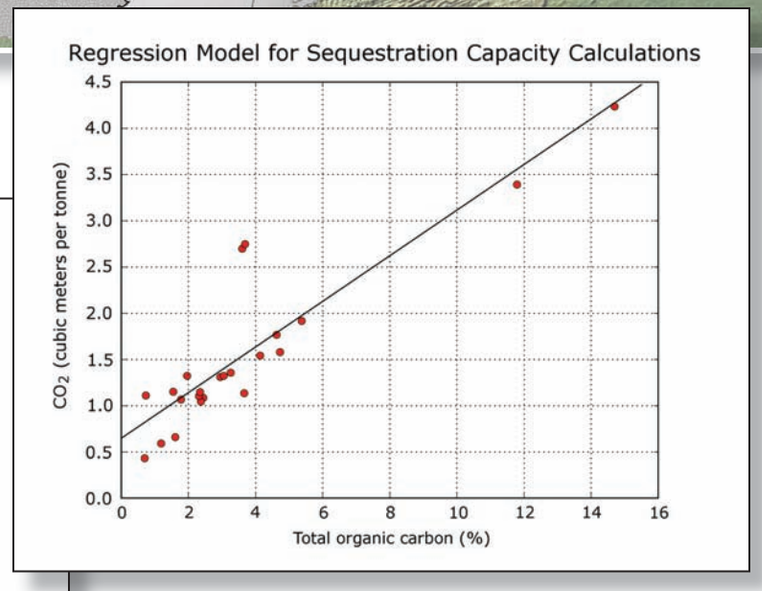
The MRCSP Region contains widespread, thick deposits of organic shales. These shales are interesting in that they are often multifunctional, acting as seals for underlying reservoirs, as source rocks for oil and gas reservoirs, and as unconventional gas reservoirs themselves. Analogous to sequestration in coal beds, CO_2 injection into unconventional carbonaceous shale reservoirs could be used to enhance existing gas production. As an added feature, it is believed the carbonaceous shales would adsorb the CO_2 into the shale, permitting long-term CO_2 storage, even at relatively shallow depths.

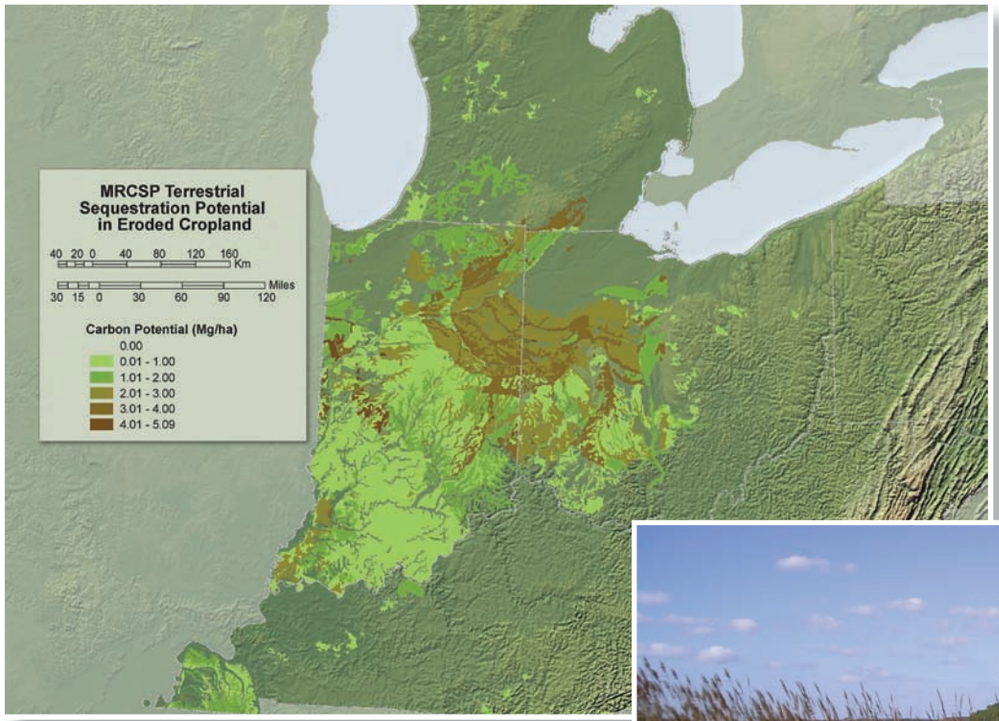
Organic shales are thickest in Kentucky, Ohio, West Virginia, and portions of Pennsylvania. In addition, shales are present throughout the Michigan Basin. Analysis of these rock formations indicates that they may have the capacity to sequester up to 45,000 million metric tons (49,600 million tons) of CO_2.

An outcrop of the Devonian Ohio shale in eastern Kentucky









Restored tidal marshes at Blackwater National Wildlife Refuge, Maryland

MRCSP Terrestrial Opportunities

Terrestrial ecosystems in the MRCSP states offer a viable opportunity for carbon sequestration because of the extensive farmlands, wetlands, minelands, and forests in the Region. More than 228,000 km^2 (88,000 mi^2) of land in the MRCSP Region could be utilized for enhanced carbon sequestration. Studies of the Region have shown the potential to sequester 144 million metric tons (159 million tons) of CO_2 per year in croplands, marginal lands, minelands, and wetlands (total emissions from large stationary sources in the MRCSP Region are approximately 765 million metric tons (843 million tons) of CO_2 per year). Tests are being conducted to demonstrate carbon sequestration through improved agriculture management practices for farmers in marginal and nonmarginal cropland areas. Studies on tidal marsh areas are also underway to determine how to maximize terrestrial carbon sequestration in wetland areas and minimize decomposition. Finally, surface mining areas are being tested to determine the amount of carbon sequestration that may be achieved in reclaimed minelands. Although the potential storage capacity is not as great in terrestrial systems as in geologic systems, terrestrial systems offer other benefits such as improvements in water quality, reduced fertilization use, habitat improvement, and reduced particulates that make terrestrial sequestration attractive in the Region.

Testing at restored tidal marshes at Blackwater National Wildlife Refuge, Maryland

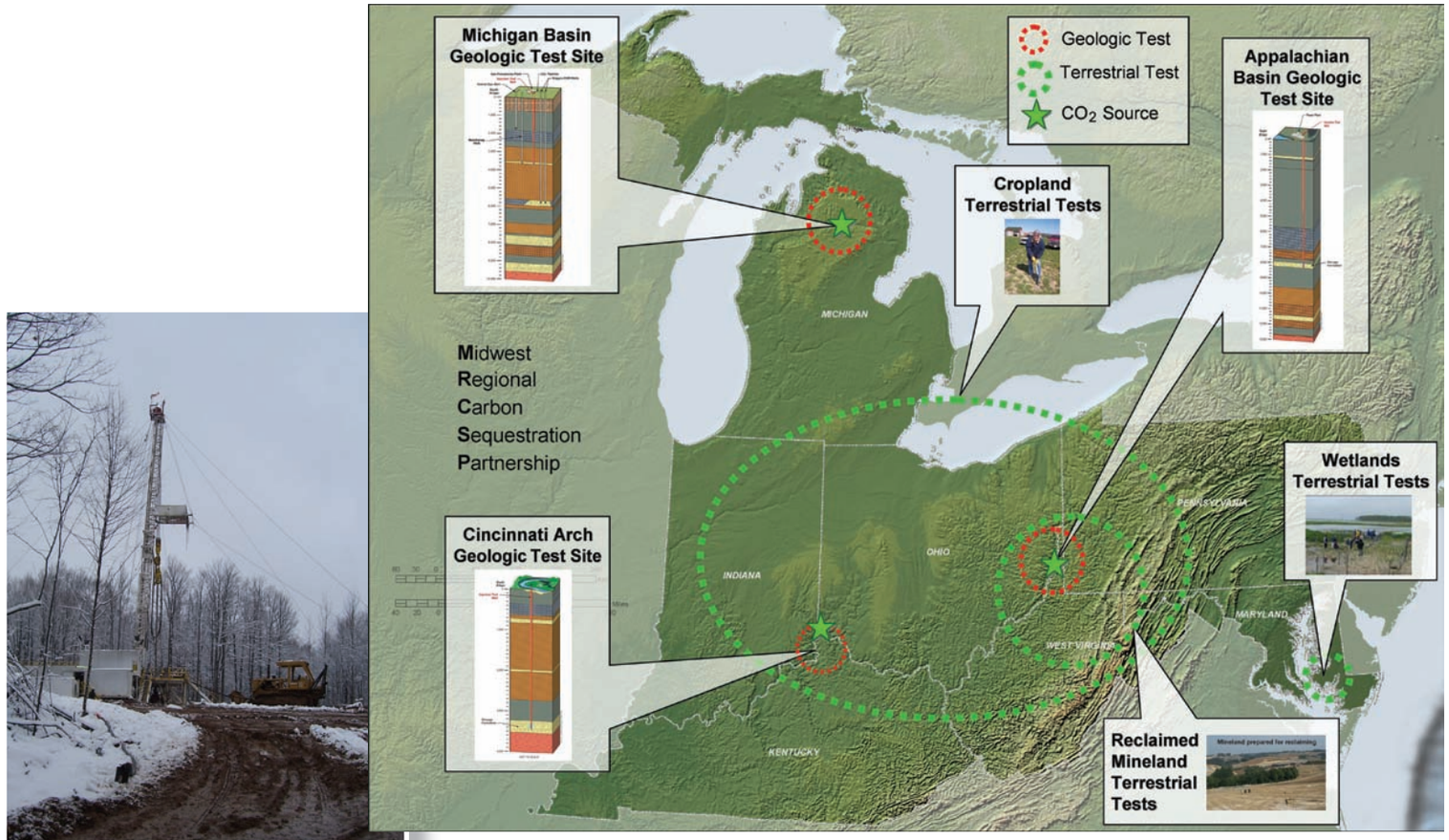
Terrestrial Sequestration Potential in the MRCSP Region

Category	Area (Mha)	Sequestration Potential (million metric tons CO_2/year)							
		IN	KY	MD	MI	OH	PA	WV	*Total*
Cropland	10.7	4.4	1.1	0	3.7	4	0.4	0	*14*
Eroded Cropland	1.6	6.6	0	0	0.7	4	0	0	*11*
Marginal Land (Forest)	6.5	19.5	16.9	3.7	16.2	17.7	17.7	7.7	*99*
Mineland	0.6	0	0.7	0.4	0.7	0.7	1.1	1.8	*6*
Wetland	3.4	2.9	0	1.8	8.8	0.7	0	0	*14*
Total	***22.8***	***33.5***	***18.8***	***5.9***	***30.2***	***27.2***	***19.1***	***9.6***	***144***

MRCSP Field Tests

Given the diversity of storage opportunities in the Region, the overall approach for the MRCSP field tests is to evaluate many different sequestration options in real-world settings. Three geologic and three terrestrial field sites were identified to test the safety and effectiveness of carbon sequestration in the Region through a series of focused field tests of sequestration technologies. The field tests should provide meaningful results for the entire Region, with the added benefit of examining technical and economic aspects of carbon capture and storage.

Geologic tests are planned along distinct, regional geologic features including the Appalachian Basin, Cincinnati Arch, and Michigan Basin. Tests will be performed at existing power plants in Eastern Ohio and Northern Kentucky and an oil and gas field in the northern portion of lower Michigan. The general methodology for each site is to characterize the deep rock layers, drill test wells, perform limited CO_2 injection tests, monitor the injected CO_2, and evaluate the sequestration process as it applies to the Region.



Appalachian Basin geologic test site.

Terrestrial sequestration tests are planned at croplands, reclaimed mineland areas, and wetlands. The objective of these tests is to measure the potential increase in carbon sequestration with different farming and land use practices. This field work is designed to quantify the actual carbon sequestration possible in these environments.

Cropland terrestrial sequestration test site.

Along with the field tests, a thorough stakeholder outreach effort is underway to communicate project progress to the local community, general public, and scientific community. In addition, research is being performed to develop a regulatory framework for sequestration, characterize additional geologic targets, and develop carbon capture technologies suitable for sources in the Region.

Seismic survey for Appalachian Basin site.